THE EFFECT OF WAVES AND WAVE BREAKING ON IR SST (321SR) AND MODULATION OF SKIN TEMPERATURE BY OCEAN SWELL WAVES (AASERT) AND IR SYSTEM FOR AIRBORNE MEASUREMENTS OF LITTORAL ZONE (DURIP)

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LONG-TERM GOAL

This research is to develop infrared remote sensing techniques to quantify exchange processes at the air-sea interface utilizing similarity scaling for the fluxes of heat, gas, and momentum. The primary focus is to understand the spatial and temporal evolution of the ocean thermal boundary layer through infrared detection of the bulk-skin temperature difference. We also address the development of laboratory and in situ calibration techniques, which are essential to making measurements of useful accuracy.

SCIENTIFIC OBJECTIVES

The objectives are to (1) establish accurate, in situ measurement techniques, (2) model the modulation of skin temperature by long waves, (3) utilize IR measurements to infer the energy dissipation rate due to large scale wave breaking, (4) investigate microscale wave breaking, and (5) determine the effect of wind-induced surface roughness on emissivity.

APPROACH

The approach is to use field and laboratory measurements to quantify the variability of IR SST and as a guide to modeling the effect of waves and wave breaking. No field experiments were performed in FY97. Laboratory measurements are ongoing in the University of Washington wavetank.

WORK COMPLETED

Completed works include the following:

1. With post-doctoral research fellow Dr. Gary Wick, a model for the modulation of skin temperature by swell waves has been developed and compared with observations (Wick and Jessup, 1997);
2. With graduate student Mr. Chris Zappa and Professor Harry Yeh (Dept. of Civil Engineering, Univ. of Wash.), the utility and potential of IR techniques for defining and quantifying microscale wave breaking has been demonstrated (Jessup, et al., 1997a). Mr. Zappa, who is supported under the AASERT, passed his general exam in August, 1997; and

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3. Under the DURIP awarded in FY97, a survey was made of the commercially available imagers and the top choice was rented for detailed evaluation. A significant effort has been required to ensure proper calibration during field operations. The purchase decision has been finalized and expected delivery is by the end of 1997.

RESULTS

1. *Measurement and Modeling of Skin Temperature Modulation by Swell Waves*:
   We have evaluated the modulation of the ocean skin temperature by swell waves expected to result from three mechanisms: compression of the thermal boundary layer, localized enhancement of the wind stress and heat flux along the wave form, and preferential breaking on the front face of the swell. To simulate the preferential-breaking mechanism, we developed a promising new model that simulates the disruption and subsequent recovery of the skin layer by both wave breaking and surface renewal events. We compared the temperature modulation predicted by the models of the various mechanisms with observations by *Jessup and Hesany* [1996] of the modulation in the open ocean. The preferential-breaking mechanism best explained the overall temperature modulation observed when the wind and swell were aligned

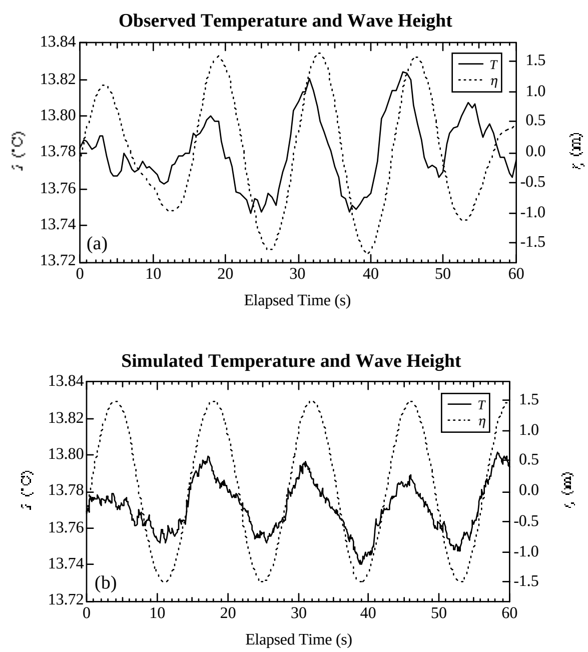

Figure 1. Shows a Comparison of Measurements and the Model Results

Figure 1. Comparison of the temperature modulation simulated with our new preferential breaking model and the observed modulation. The top panel shows the observed temperature T (solid curve) and surface displacement h (dashed curve) and the bottom panel shows the results of the simulation. While matching the observed mean • T, the simulation properly predicts that the peak skin temperature occurs on the front face of the wave and reasonably approximates the observed magnitude of the temperature fluctuations.

By assuming that preferential breaking occurs on the front face of swell waves when the wind and swell are aligned and taking the time evolution of the skin temperature to be governed by molecular diffusion, our new model simultaneously approximated the mean skin temperature and the amplitude of the observed temperature modulation in most conditions. These encouraging results suggest that short gravity waves may indeed preferentially break on the forward face of the swell and that this breaking may be responsible for the observed modulation. Our best overall results were obtained when the effects of preferential breaking and the modulation of the heat flux were both included. While several parameters in the model require further theoretical development to evaluate the model fully and make it predictive, it has demonstrated the potential to explain the observed modulation while the models of the other mechanisms individually could not; and

2. *Defining and Quantifying Microscale Breaking Waves using IR techniques*:
This work was stimulated by earlier research on the relationship of the IR signature of large-scale breaking waves to energy dissipation [*Jessup et al., 1997b]*. Microscale breaking waves disrupt the skin layer and produce thermal surface signatures that can be quantified by infrared imaging techniques. As far as we know, we have made the first published measurements of the infrared signature of microscale breaking waves. Figure 2 illustrates the characteristic features of microscale breaking wave and Figure 3 shows our conceptual model for the skin layer disruption that we measure.

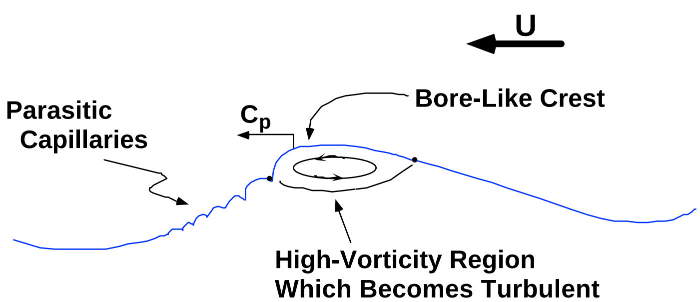

Figure 2. Characteristic Features of Microscale Breaking Waves

Figure 2. The characteristic feature of a microscale breaking wave is a bore-like crest with parasitic capillary waves riding along the forward face; U is the wind speed and Cb is the crest speed of the microscale breaking wave. (Adapted from Ebuchi, et al., 1987.)

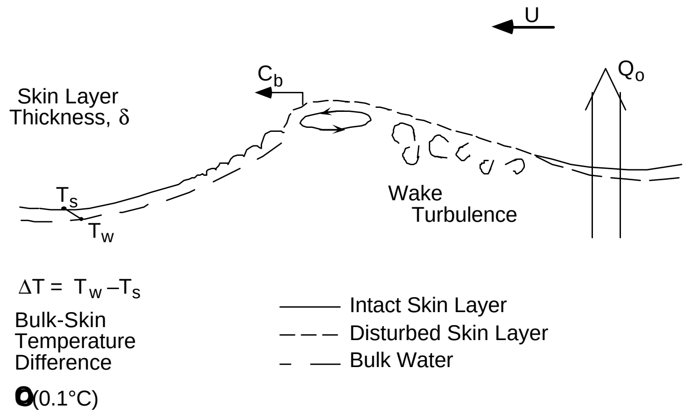

Figure 3. Conceptual Model of Disruption of the Cool Skin Layer by a Microscale Breaking Wave

Figure 3. Conceptual model of disruption of the cool skin layer by a microscale breaking wave which leads to the thermal signature detectable by infrared imaging. The cool skin is disrupted and replaced by warmer bulk fluid from below. The bulk–skin temperature difference, • T, across the cool skin layer of thickness, d, is supported by the net heat flux, Qo.

We have demonstrated the ability to obtain the frequency of occurrence and the areal coverage of microscale wave breaking. Using laboratory measurements, we have shown that the fractional area of water surface affected by microscale wave breaking can be substantial under a moderately forced laboratory wind-wave field. The frequency of microscale wave breaking was roughly one-third that of the dominant wave. Evidence from the literature suggests that downward "bursting" phenomena observed beneath laboratory wind waves are likely produced by microscale wave breaking. However, the frequency of microscale wave breaking we measure is significantly higher than the frequency of bursting reported by others, implying that not all microscale breaking waves produce these "bursts." Other readily available quantities of interest include the rate of recovery, the intensity, and the duration of microscale wave breaking events. Examples of ocean measurements demonstrated that these techniques may also be applied in the field.

IMPACT/APPLICATION

1. *Modeling of Skin Temperature Modulation by Swell Waves*:
   The results imply that wave breaking can have an important effect on the bulk-skin temperature difference, ΔT. The scatter remaining in the present attempts to model ΔT may well be influenced by the amount of wave breaking. Future efforts to model the mean ΔT as well as the modulation of the skin temperature should benefit by attempting to quantify and incorporate a measure of the amount of breaking. If wave breaking proves to significantly influence ΔT, its effects will also have an important impact on other air–sea exchange processes including gas transfer; and

2. *Defining and Quantifying Microscale Breaking Waves using IR techniques*:
   The infrared techniques we have developed provide a new and objective measurement method for identifying and quantifying microscale breaking waves despite their low visual

contrast and small scale. Furthermore, our observations suggest that the infrared signature of microscale wave breaking may serve as a practical means of defining the phenomenon itself. The results demonstrate that infrared techniques can provide the information necessary to quantify the breaking process for inclusion in models of air-sea heat and gas fluxes, as well as unprecedented details on the origin and evolution of microscale wave breaking.

TRANSITIONS

The potential significance of microscale breaking waves in radar backscatter has been indicated by recent efforts to model observations of microwave backscatter near grazing (Trizna and Carlson, 1996) and at large incidence (Plant, 1997). During the next biennium, field and laboratory IR measurements of microscale wave breaking will be made in conjunction with microwave measurements by Dr. W. J. Plant (APL-UW).

RELATED PROJECTS

This work is related to a NSF-funded collaboration with Dr. W. E. Asher (APL-UW) to determine the role of microscale wave breaking in air-sea gas transfer. The work uses similar techniques and laboratory efforts are combined in order to reduce costs.

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